



UNIVERSITI PUTRA MALAYSIA

**EFFICACY OF BACILLUS THURINGIENSIS BERLINER AGAINST
METISA PLANA WALKER AND ITS APPLICATION USING THERMAL
FOGGER AND MISTBLOWER**

TAN SEK YEE.

FP 2004 34

**EFFICACY OF *BACILLUS THURINGIENSIS* BERLINER AGAINST
METISA PLANA WALKER AND ITS APPLICATION USING
THERMAL FOGGER AND MISTBLOWER**

By

TAN SEK YEE

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,
in Fulfilment of the Requirements for the
Degree of Master of Agricultural Science**

April 2004



To

My Parents and Prof. Khoo

Because of them,

“ I have a new love for that glittering instrument, the human soul.

It is a lovely and unique thing in the universe.

It is always attacked and never destroyed — because ‘Thou mayest.’”

East of Eden

By John Steinbeck



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Agricultural Science

**EFFICACY OF *BACILLUS THURINGIENSIS* BERLINER AGAINST
METISA PLANA WALKER AND ITS APPLICATION USING
THERMAL FOGGER AND MISTBLOWER**

By

TAN SEK YEE

April 2004

Chairman: Professor Yusof Ibrahim, Ph.D.

Faculty: Agriculture

The effectiveness of *Bacillus thuringiensis* Berliner (*Bt*) against the bagworm, *Metisa plana* Walker and its application using thermal fogger and mistblower was studied in three-year old oil palms.

Initially, a standardized rearing protocol of the bagworm was established to produce healthy test insects. *Metisa plana* was reared on oil palm seedlings from eggs surface-sterilized for one hour in 8% formaldehyde. This sterilization regime did not affect the egg hatchability and it significantly ($P<0.05$) increased the survivorship of the first to second instar larvae when compared to larvae hatched from unsterilized eggs.

Following a laboratory bioassay conducted against the third and fifth instar larvae at temperatures of 25-29°C and 50-80% relative humidity, formulations from both *Bt*



subsp. *kurstaki*: Dipel® ES, Dipel® DF, Dipel® WP and ABG-6429 FC; and *Bt* subsp. *aizawai*: Florbac® SC and Xentari® WG were shown to be effective on the bagworm.

Evaluation on the suitability and effectiveness of portable thermal fogging (PulsFog®-K10 and AgroFog® AF 35) and mistblower (Solo® Master 412) application of *Bt* (Dipel® ES®) against *M. plana* in three-year old oil palm revealed that when water was used as the diluent in spray mixtures, efficacious activity was achieved which was attributed from the formation of an adequately stable emulsion. For both types of applicators, the kill of *M. plana* was shown to be positively dependent on droplet densities and concentrations of *Bt*. In the field trial on three-year old oil palm, AgroFog® AF 35 with AFX Fogging Solution and Solo® Master 412 Knapsack Mistblower were shown to give effective horizontal throw of 6 m whereas PulsFog®-K10 was only 2 m. Under the condition of these experiments, cost effectiveness analysis showed that the use of portable fogger to apply *Bt* formulation to control *M. plana* was not as cost-effective, practical or suitable as knapsack mistblower. The predicted kill of the bagworm obtained by mistblower was satisfactory and higher (50-92%) compared to thermal fogger (38-46%) at the middle and top strata of the oil palm. The poor deposition rates from fogging application in the palm increased the usage of Dipel® ES and AFX Fogging Solution thus incurred higher cost. Furthermore, the fogging application was limited to early morning or late evening, and that also incurred higher labour cost, notwithstanding the possibility of labour shortage. Comparatively, the use of mistblower gave higher deposition rates that reduced the rates of Dipel® ES per hectare thus saved cost. Mistblower is also easily available, versatile and can be used during the daytime.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Master Sains Pertanian

**KEBERKESANAN *BACILLUS THURINGIENSIS* BERLINER TERHADAP
METISA PLANA WALKER DAN APPLIKASINYA DENGAN
ALAT PENGABUT DAN PENYEMBUR KABUS**

Oleh

TAN SEK YEE

April 2004

Chairman: Profesor Yusof Ibrahim, Ph.D.

Fakulti: Pertanian

Keberkesanan *Bacillus thuringiensis* Berliner (*Bt*) terhadap ulat bungkus, *Metisa plana* Walker dan aplikasinya dengan pengabut dan penyembur kabus telah dikaji pada kelapa sawit berumur tiga tahun.

Pada permulaannya, satu protokol standard untuk pembelaan ulat bungkus telah dihasilkan untuk memperoleh ulat yang sihat untuk ujian. *Metisa plana* yang menetas daripada telur yang telah disterilkan permukaannya selama satu jam dengan 8% formaldehid telah dipelihara di atas anak semaian kelapa sawit. Kaedah pensterilan ini tidak menjejaskan penetasan telur dan ia meningkatkan kemandirian ulat dengan signifikannya ($P < 0.05$) daripada instar pertama ke instar kedua berbanding ulat daripada telur yang tidak disterilkan.

Berikutan bioasai di makmal yang dijalankan ke atas instar ketiga dan kelima di bawah keadaan suhu 25-29°C dan 50-80% kelembapan bandingan, formulasi daripada kedua-dua *Bt* subsp. *kurstaki* Berliner: Dipel® ES, Dipel® DF, Dipel® WP dan ABG-6429 FC; dan *Bt* subsp. *aizawai* Berliner: Florbac® SC and Xentari® WG telah didapati berkesan pada ulat bungkus.

Penilaian kesesuaian dan keberkesanan di dalam penggunaan pengabut (PulsFog®-K10 dan AgroFog® AF 35) dan penyembur kabus (Solo® Master 412) untuk menyembur *Bt* ke atas *M. plana* pada kelapa sawit berumur tiga tahun telah menunjukkan bahawa apabila *Bt* (Dipel® ES) dicampurkan ke dalam air, efikasi telah didapati oleh kerana disebabkan pembentukan emulsi yang stabil di dalam campuran semburan. Kedua-dua jenis applikasi ini menunjukkan bahawa kawalan *M. plana* bergantung secara positif kepada kepadatan titisan dan kepekatan *Bt*. Dalam aplikasi penyemburan pada pokok-pokok kelapa sawit berumur tiga tahun, AgroFog® AF 35 dengan cecair pengabutan AFX dan penyembur kabus Solo® Master 412 telah memberi jarak semburan mendatar 6 m yang berkesan manakala PulsFog®-K10 hanya memberi 2 m. Di bawah keadaan kajian ini, analisis keberkesanan kos menunjukkan penggunaan alat pengabut untuk formulasi *Bt* bagi mengawal *M. plana* adalah kurang kos-berkesan, praktikal atau sesuai berbanding dengan alat penyembur kabus. Jangkaan kematian ulat bungkus yang diperolehi daripada penyemburan kabus adalah memuaskan and lebih tinggi (50-92%) berbanding dengan alat pengabutan (38-46%) di stratum tengah and atas pokok kelapa sawit. Kadar taburan titisan yang rendah dari penyemburan kabut pada pokok kepala sawit telah meningkatkan penggunaan Dipel® ES dan AFX

Fogging Solution, oleh itu kos telah meningkat tinggi. Tambahan pula, kerja pengabutan agak terhad pada waktu awal pagi atau lewat petang dan ini telah meningkatkan kos buruh, malahan berkemungkinan akan mengalami kesukaran mendapat pekerja. Akan tetapi, penggunaan penyembur kabus memberi kadar taburan titisan yang lebih tinggi yang mana mengurangkan kadar penggunaan Dipel® ES per hektar maka dengan itu, kos dijimatkan. Alat penyembur kabus juga mudah didapati dan boleh digunakan pada bila-bila masa termasuk waktu kerja siang hari.

ACKNOWLEDGEMENTS

This project has been a challenging one. I would never have got through this study without the help from various parties that I am deeply indebted with. I would like to take this opportunity to express my most sincere appreciation to my supervisory committee members Professor Dr. Khoo Khay Chong, Professor Dr. Yusof Ibrahim and Associate Professor Dr. Dzolkhifli Omar, for their ideas, advices, criticisms and encouragements made in the preparation of this thesis. I am particularly thankful to Prof. Khoo who was willing to train me despite all the obstacles faced throughout the project.

This project is funded by Valent BioSciences Corporation, U.S.A.. I would like to thank them for their support in this project. I appreciate the interest and help given by Mr. Tay Boon Liang and Dr. Andrew C. Rath throughout this project.

Egg collections of *Metisa plana* were made possible by the contacts given by Mr. Chung Gait Fee, Dr. Ho Cheng Tuck, Mr. R. Balasubramaniam, Mr. Eow Wat Son, Mr. Liew Voon Kheong and Dr. Ang Ban Na. Their supports, advices, insights into the study of the bagworms and sometimes, free supply of the eggs are of great value to me. I am also deeply grateful to the helps given by various oil palm estates at Niyor and Paloh area in Johor, Bukit Rajah and Sungai Buloh area in Selangor and Sungkai, Perak when collecting the bagworm eggs.



My gratitude is also due to Mr. Yoong Ching Pin and Mr. Muhammad Rizal from Kirby Estate, who arranged workers for me in conducting field trials in the estate. I am deeply thankful to Mr. Talib Samat, Mr. Ismail Yusa, Miss Khor Siew Eim, Mr. Dadan Ramdani for their sacrifices in helping me in the field. I am particularly thankful to Mr. Talib Samat for his sincere effort to accompany and working with me whether in the early morning or late evening or throughout the day. Additionally, I would also like to thank Elsie, Melvin and Hooi Ling for their moral support during the course of my study.

In fogging operation, I am grateful to Agro Swingtec Sdn. Bhd. for their support in this project. Thank you for lending a fogging machine and supplying a fogging carrier to this study. Besides that, technical advises and oil samples given respectively by The Foggers Company and Cheong Trading is appreciated.

Finally, I would like to express my deep love to my family members who are always there for me during my growing-up years. They have been a source of inspiration and support to me. To my mum and dad, I love you.



I certify that an Examination Committee met on 26th April 2004 to conduct the final examination of Tan Sek Yee on her Master of Agricultural Science thesis entitled “Efficacy of *Bacillus thuringiensis* Berliner Against *Metisa plana* Walker and its Application Using Thermal Fogger and Mistblower” in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Rita Muhammad, Ph.D.

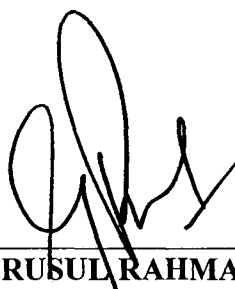
Associate Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Chairman)

Yusof Ibrahim, Ph.D.

Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)

Dzolkhifli Omar, Ph.D.

Professor
Faculty of Agriculture
Universiti Putra Malaysia
(Member)



GULAM RUSUL RAHMAT ALI, Ph.D.

Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 17 JUN 2004

This thesis submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirements for the degree of Master of Agricultural Science. The members of the Supervisory Committee are as follows:

Yusof Ibrahim, Ph.D.

Professor

Faculty of Agriculture

Universiti Putra Malaysia

(Chairman)

Dzolkhifli Omar, Ph.D.

Professor

Faculty of Agriculture

Universiti Putra Malaysia

(Member)



AINI IDERIS, Ph.D.

Professor/Dean

School of Graduate Studies

Universiti Putra Malaysia

Date : 10 JUL 2004



DECLARATION

I hereby declare that the thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at UPM or other institutions.



TAN SEK YEE

Date : 10th July 2004.

TABLE OF CONTENTS

	Page
DEDICATION	ii
ABSTRACT	iii
ABSTRAK	v
ACKNOWLEDGEMENTS	viii
APPROVAL	x
DECLARATION	xii
LIST OF TABLES	xviii
LIST OF FIGURES	xxi
LIST OF APPENDICES	xxv
LIST OF ABBREVIATIONS/NOTATIONS/GLOSSARY OF TERMS	xxxvii
 CHAPTER	
1 INTRODUCTION	1
2 LITERATURE REVIEW	5
2.1 The Psychidae	5
2.2 Bagworms: Pest of Oil Palm in Malaysia	6
2.2.1 <i>Metisa plana</i> Walker	8
2.2.2 Integrated Pest Management of the Bagworms	12
2.2.3 Insecticides and Application Techniques Against the Bagworm	14
2.3 <i>Bacillus thuringiensis</i>	16
2.3.1 <i>Bt</i> against the Bagworms	18
2.4 Effective Pesticide Application	19
2.4.1 Ground Application against the Bagworms in Malaysia	20
2.4.1.1 Use of Mistblower	22
2.4.1.2 Thermal Fogging	23
3 REARING OF THE BAGWORM <i>METISA PLANA</i>	24
3.1 Introduction	24
3.2 Experiment 1: Effect of Formaldehyde as Egg Surface Sterilization and Its Effect on Hatchability	25
3.2.1 Materials and Method	25
3.2.2 Results	28
3.2.3 Discussion	29
3.2.4 Conclusion	29



3.3	Experiment 2: Survivorship of Early Instar Larvae from Surface Sterilized Eggs Compared to Unsterilized Eggs	29
3.3.1	Materials and Method	29
3.3.2	Results	31
3.3.3	Discussion	32
3.3.4	Conclusion	33
3.4	Rearing Protocol of the Bagworm <i>Metisa plana</i>	34
3.4.1	Egg Collection from Oil Palm Field	34
3.4.2	Egg Preparation	35
3.4.3	Egg Surface Sterilization	38
3.4.4	Egg Incubation	39
3.4.5	Rearing of the <i>Metisa plana</i> Larvae	42
3.4.5.1	Rearing in the Laboratory	42
3.4.5.2	Rearing on Oil Palm Seedlings in Screen House	42
4	EFFICACY OF <i>BACILLUS THURINGIENSIS</i> AGAINST <i>METISA PLANA</i>	44
4.1	Introduction	44
4.2	Experiment 1: Efficacy of Various <i>Bt</i> Formulations on <i>Metisa plana</i>	45
4.2.1	Materials and Method	45
4.2.2	Results	48
4.2.3	Discussion	54
4.2.4	Conclusion	57
5	USE OF PULSFOG® K-10 TO APPLY <i>BACILLUS THURINGIENSIS</i> AGAINST <i>METISA PLANA</i>	58
5.1	Introduction	58
5.2	Efficacy of <i>Bacillus thuringiensis</i> against <i>Metisa plana</i> under Conventional Fogging Application	59
5.2.1	Experiment 1: Effect of Thermal Fogging of <i>Bacillus thuringiensis</i> on the Survivorship of <i>Metisa plana</i>	59
5.2.1.1	Materials and Method	59
5.2.1.2	Results	60
5.2.1.3	Discussion	60
5.2.1.4	Conclusion	62
5.2.2	Experiment 2: Emulsion Stability of Dipel® ES in Diesel and Water	63
5.2.2.1	Materials and Method	63
5.2.2.2	Results	63
5.2.2.3	Discussion	64
5.2.2.4	Conclusion	66
5.3	A Standardized Fogging Condition: Fogging Tunnel	66
5.3.1	Development of a Fogging Tunnel	66

5.3.2	Working Procedures of the Fogging Tunnel	68
5.3.3	Droplet Characteristics of PulsFog® K-10 in the Fogging Tunnel	68
5.3.4	Development of the Scorecards of Fog Droplet Densities	69
5.4	Feasibility of Thermal Fogging with <i>Bacillus thuringiensis</i> against <i>Metisa plana</i>	71
5.4.1	Experiment 1: Efficacy of <i>Bacillus thuringiensis</i> against <i>Metisa plana</i> Applied by PulsFog® K-10 in the Fogging Tunnel	71
5.4.1.1	Materials and Method	71
5.4.1.2	Results	72
5.4.1.3	Discussion	74
5.4.1.4	Conclusion	76
5.4.2	Experiment 2: Determination of Suitable Nozzle Size for PulsFog® K-10 in the Field	77
5.4.2.1	Materials and Method	77
5.4.2.2	Results	78
5.4.2.3	Discussion	79
5.4.2.4	Conclusion	80
5.4.3	Experiment 3: Efficacy of <i>Bacillus thuringiensis</i> against <i>Metisa plana</i> Applied by PulsFog® K-10 in Oil Palm Field	81
5.4.3.1	Materials and Method	81
5.4.3.2	Results	82
5.4.3.3	Discussion	84
5.4.3.4	Conclusion	87
6	USE OF AGROFOG® AF35 IN APPLYING <i>BACILLUS THURINGIENSIS</i> AGAINST <i>METISA PLANA</i>	89
6.1	Introduction	89
6.2	Droplet Characteristics of Agrofog® AF35	90
6.2.1	Experiment 1: Determination of Suitable Nozzle Size for Agrofog® AF35 in the Field	90
6.2.1.1	Materials and Method	90
6.2.1.2	Results	91
6.2.1.3	Discussion	92
6.2.1.4	Conclusion	92
6.2.2	Experiment 2: Effect of Dipel® ES and AFX Fogging Solution on the Droplet Characteristics of Agrofog® AF35	93
6.2.2.1	Materials and Method	93
6.2.2.2	Results	93
6.2.2.3	Discussion	95
6.2.2.4	Conclusion	97

6.3	Feasibility of Thermal Fogging in Applying <i>Bacillus thuringiensis</i> against <i>Metisa plana</i>	98
6.3.1	Experiment 1: Efficacy of <i>Bacillus thuringiensis</i> against <i>Metisa plana</i> Applied by Agrofog® AF35 at Various Droplet Densities in Oil Palm Field	98
6.3.1.1	Materials and Method	98
6.3.1.2	Results	98
6.3.1.3	Discussion	100
6.3.1.4	Conclusion	102
6.3.2	Experiment 2: Calibration of Agrofog® AF35 with Various Concentrations of AFX in Three-Year Old Oil Palm	103
6.3.2.1	Materials and Method	103
6.3.2.2	Results	107
6.3.2.3	Discussion	112
6.3.2.4	Conclusion	115
6.3.3	Experiment 3: Determination of the Suitable Concentration of AFX in Fogging Young Oil Palm by Agrofog® AF35	116
6.3.3.1	Materials and Method	116
6.3.3.2	Results	117
6.3.3.3	Discussion	119
6.3.3.4	Conclusion	125
7	USE OF SOLO® 412 KNAPSACK MISTBLOWER TO APPLY <i>BACILLUS THURINGIENSIS</i> AGAINST <i>METISA PLANA</i>	127
7.1	Introduction	127
7.2	Droplet Characteristics of Solo® Master 412 Knapsack Mistblower	128
7.2.1	Experiment 1: Determination of the Suitable Restrictor Setting for Solo® Master 412 Knapsack Mistblower in the Field	128
7.2.1.1	Materials and Method	128
7.2.1.2	Results	129
7.2.1.3	Discussion	130
7.2.1.4	Conclusion	130
7.2.2	Experiment 2: Effect of Dipel® ES on the Droplet Characteristics of Solo® Master 412 Knapsack Mistblower	131
7.2.2.1	Materials and Method	131
7.2.2.2	Results	131
7.2.2.3	Discussion	132
7.2.2.4	Conclusion	133
7.3	Development of Scorecards Representing Densities of Mist-Type Droplet	133

7.4	Feasibility of Mistblower in Applying <i>Bacillus thuringiensis</i> against <i>Metisa plana</i>	136
7.4.1	Experiment 1: Efficacy of <i>Bacillus thuringiensis</i> against <i>Metisa plana</i> Applied by Solo® Master 412 Knapsack Mistblower at Various Droplet Densities in the Field	136
7.4.1.1	Materials and Method	136
7.4.1.2	Results	136
7.4.1.3	Discussion	138
7.4.1.4	Conclusion	141
7.4.2	Experiment 2: Evaluation on the Spray Application of Solo® Master 412 Knapsack Mistblower with Restrictor One in Three-Year Old Oil Palm	142
7.4.2.1	Materials and Method	142
7.4.2.2	Results	144
7.4.2.3	Discussion	152
7.4.2.4	Conclusion	156
7.4.3	Experiment 3: Evalustion on the Spray Application of Solo® Master 412 Knapsack Mistblower with Restrictor Two in Three-Year Old Oil Palm	158
7.4.3.1	Materials and Method	158
7.4.3.2	Results	159
7.4.3.3	Discussion	163
7.4.3.4	Conclusion	170
8	GENERAL DISCUSSION AND CONCLUSION	172
	REFERENCES/BIBLIOGRAPHY	181
	APPENDICES	191
	BIODATA OF THE AUTHOR	288

LIST OF TABLES

Table	Page
3.1 Mean percentage hatchability (\pm S.D.) of <i>M. plana</i> eggs surface sterilized with four concentrations of formaldehyde at four different immersion times.	28
3.2 Mean percentage survivorship (\pm S.D.) of early instar larvae of <i>M. plana</i> from sterilized and unsterilized eggs.	31
4.1 List of <i>Bt</i> formulations and concentrations tested on the specific instar stages of <i>M. plana</i> .	45
4.2 The minimum concentrations of various <i>Bt</i> formulations and the number of DAT to achieve satisfactory larval mortality (70-100%) of the L3 and L5 of <i>M. plana</i> .	48
4.3 Recommended rates of the various <i>Bt</i> formulations on the bagworms, where possibly available obtained from the manufacturer.	54
5.1 Description of emulsion stability of 160 mL/L of Dipel® ES suspended in water and diesel at one, ten and 30 minutes after shaking.	63
5.2 Score system of various levels of fog DD.	69
5.3 VMD, NMD and ratio of VMD to NMD of three nozzle sizes of PulsFog® K-10 applied in field at 2 m from point of fogging.	78
5.4 Mean number of droplets/cm ² \pm S.D. at 2, 4 and 6 m from PulsFog® K-10 with application of 40 and 120 mL/L of Dipel® ES using three nozzle sizes.	79
5.5 Mean percentage mortality \pm (S.D.) of the L3 and L5 of <i>M. plana</i> when exposed to the following treatments in fogging tunnel and field.	85
6.1 Number of droplets/cm ² \pm S.D. at 2, 4 and 6 m from Agrofog® AF 35 applying water with three nozzle sizes.	91
6.2 Number of droplets/cm ² ^a \pm S.D. at 2, 4 and 6 m from application of various concentrations of Dipel® ES by Agrofog® AF 35 fitted with nozzle size 1.2 mm.	94



6.3	Number of droplets/cm ² ± S.D. at 2, 4 and 6 m from application of various concentrations of AFX Fogging Solution by Agrofog® AF 35 fitted with nozzle size 1.2 mm.	95
6.4	The lowest concentrations of Dipel® ES and level of DD applied by Agrofog® AF 35 and PulsFog® K-10 in field that would give a satisfactory kill (74 to 84%) of the L3 and L5 of <i>M. plana</i> in laboratory efficacy test.	101
6.5	Ranges of mean droplets /cm ² at the upper (U) and lower (L) surfaces of leaflets at the front and back canopy of three-year old oil palm when fogging various concentrations of AFX by using Agrofog® AF 35 (Appendix 6.21).	111
6.6	Mean number of droplets/cm ² (±S.D.) ^x deposited on the upper surface of foliage of the three-year old oil palms with 10 to 25% of AFX applied by Agrofog AF® 35.	118
6.7	Percentage mortality (± SD) of the L3 and L5 of <i>M. plana</i> in lab after 5 days of exposure to oil palm foliage that was applied by Agrofog® AF 35 in field at various concentrations of Dipel® ES and droplet densities.	119
6.8	Important information on the calibration of Agrofog® AF 35 in three-year old oil palms and its cost-effectiveness analysis of using the fogger to apply Dipel® ES in AFX aqueous suspension against <i>M. plana</i> based on one hectare of the palms.	121
7.1	Scoring system of the densities of mist-type droplet.	134
7.2	The minimum concentrations of Dipel® ES and level of DD applied by Solo® Master 412 knapsack mistblower in the field for a satisfactory kill (70 to 90%) of the L3 and L5 of <i>M. plana</i> in laboratory efficacy test.	139
7.3	Important interactions with significant and almost significant effects.	145
7.4	Mean number of water droplets/cm ² (±S.D.) ^a deposited on upper and lower surfaces of leaflets of three years old oil palm applied by Solo® Master 412 knapsack mistblower at four various spray durations per palm.	145

7.5	Highest (H) and lowest (L) ranges of mean droplets/cm ² at upper surface of leaflets at top, middle and bottom strata of three-year old palm when sprayed with Solo® Master 412 knapsack mistblower fitted with restrictor one for 1.0, 1.5, 2.0 and 2.5 minute/s of spray duration per palm.	151
7.6	The predicted kill of third and fifth instar larvae of <i>M. plana</i> at the top and middle strata of three-year old oil palm from combinations of spray applications with various concentrations of Dipel® ES and spray durations per palm using Solo® Master 412 knapsack mistblower with restrictor one.	155
7.7	Important interactions with significant and no significant effects.	160
7.8	Highest (H) and lowest (L) ranges of mean droplets/cm ² at upper surface of leaflets at top, middle and bottom strata of three-year old palm when sprayed by Solo® Master 412 knapsack mistblower with combinations of restrictor setting and spray duration per palm.	163
7.9	Predicted kill of the third and fifth instar larvae of <i>M. plana</i> at the top and middle strata of three-year old oil palm from combinations of spraying application with various concentrations of Dipel® ES, restrictor settings and spray durations per palm by using Solo® Master 412 knapsack mistblower.	165
7.10	Important information on the calibration of Solo® Master 412 knapsack mistblower on three-year old oil palm and its analysis of cost-effectiveness in using the machine to apply Dipel® ES against the bagworm, <i>M. plana</i> in one hectare of the oil palms ^a .	166
7.11	Comparison of cost-effectiveness analysis between Agrofog® AF 35 (Agro) and Solo® Master 412 knapsack mistblower (Solo) when used to apply <i>Bt</i> , Dipel® ES against <i>M. plana</i> .	168

LIST OF FIGURES

Figure		Page
2.1	Feeding marks of <i>M. plana</i> on foliage of oil palm.	7
2.2	Severe damage to oil palm crown caused by <i>M. plana</i> .	7
2.3	Seventh instar larva of <i>M. plana</i> .	10
3.1	<i>M. plana</i> eggs at black head stage.	26
3.2	The inverted petri dish for egg incubation.	27
3.3	Clip-On leaf cage: (A) Two-dimensional view, (B) Three-dimensional view.	30
3.4	Male cocoon of <i>M. plana</i> with pupal case protruding from posterior end.	36
3.5	Method of dissecting the female cocoon.	37
3.6	Method to discard the adult female from within the pupal cuticle.	37
3.7	The setting of materials for rinsing surface sterilized eggs of <i>M. plana</i> .	40
3.8	Setting of egg incubators with: (A) petri dish 9 cm in diameter and (B) 100 mL specimen jar.	41
4.1	Device used for caging <i>M. plana</i> on treated excised oil palm leaflets. At left: side view of the cages, and right: front view.	47
4.2	The levels of kill achievable with the L3 and L5 of <i>M. plana</i> at various concentrations of Dipel® DF on the third and seventh DAT. The vertical lines are standard errors of means. Sources obtained from Appendices 4.1 and 4.2.	49
4.3	The levels of kill achievable with the L3 and L5 of <i>M. plana</i> at various concentrations of Dipel® ES on the third and seventh DAT. Vertical lines are standard errors of means. Sources obtained from Appendices 4.3 and 4.4.	50

4.4	The levels of kill achievable with the L3 and L5 of <i>M. plana</i> at various concentrations of Florbac® SC on the third and seventh DAT. The vertical lines are standard errors of means. Sources obtained from Appendices 4.5 and 4.6.	51
4.5	The levels of kill achievable with the L3 and L5 of <i>M. plana</i> at various concentrations of Xentari® WG on the third and seventh DAT. The vertical lines are standard errors of means. Sources obtained from Appendices 4.7 and 4.8.	52
4.6	The levels of kill achievable with the L3 of <i>M. plana</i> at various concentrations of Dipel® WP on the third and seventh DAT. The vertical lines are standard errors of means. Sources obtained from Appendix 4.9.	53
4.7	The levels of kill achievable with the L3 of <i>M. plana</i> at various concentrations of ABG-6429 FC on the third and seventh DAT. The vertical lines are standard errors of means. Sources obtained from Appendix 4.10.	53
5.1	Efficacy of <i>Bt</i> on the L5 of <i>M. plana</i> applied by PulsFog® K-10 using 160 mL/L of Dipel® ES diluted in diesel. Vertical lines are standard errors of the means. Sources were obtained from Appendix 5.2.	61
5.2	The fogging tunnel	67
5.3	Deflector setup to prevent fog from entering main tunnel.	67
5.4	Various droplet densities deposited by a fogger (PulsFog® K-10). The densities are given scores of 1 (bottom) to 6 (top).	70
5.5	Efficacy of <i>Bt</i> against L3 of <i>M. plana</i> in a fogging tunnel. Vertical lines are standard errors of means. Sources obtained from Appendix 5.7.	73
5.6	Efficacy of <i>Bt</i> against L5 of <i>M. plana</i> in a fogging tunnel. Vertical lines are standard errors of means. Sources obtained from Appendix 5.8.	73
5.7	Laboratory efficacy of <i>Bt</i> against L3 of <i>M. plana</i> in field. Vertical lines are standard errors of means. Sources obtained from Appendix 5.14.	83
5.8	Laboratory efficacy of <i>Bt</i> against the L5 of <i>M. plana</i> in field. Vertical lines are standard errors of means. Sources obtained from Appendix 5.15.	83

6.1	Laboratory efficacy of <i>Bt</i> on the L3 of <i>M. plana</i> . Treatments were applied by Agrofog® AF 35 in field at various concentrations of Dipel® ES and levels of DD. Vertical lines are standard errors of means. Sources obtained from Appendix 6.9.	99
6.2	Laboratory efficacy of <i>Bt</i> on the L5 of <i>M. plana</i> . Treatments were applied by Agrofog® AF 35 in field at various concentrations of Dipel® ES and ranges of DD. Vertical lines are standard errors of means. Sources obtained from Appendix 6.10.	99
6.3	The stratification and lay out of fogging procedure of Agrofog® AF 35 on three-year old oil palm. Q1 to Q4 represent quadrant one to four respectively. The symbol: ⊗ represents the location of pieces of white cardboard for droplets collection.	104
6.4	Number of droplets/cm ² (± S.E.) deposited on upper and lower surfaces of leaflets of top, middle and bottom strata at three frond sections located from front to back canopy of three year old oil palm of various concentrations of AFX Fogging Solution (AFX) applied by Agrofog® AF 35. In X-axis, each point represents section in oil palm canopy (part of canopy: frond section), parts of canopy: FC = front canopy and BC = back canopy, and frond sections: D = distal, M = middle and P = proximal. The four lines in each graph represent the concentrations of AFX: the symbols: ✕ = 0% AFX, △ = 10% AFX, ◇ = 25% AFX and ◻ = 50% AFX.	109
6.5	Number of droplets/cm ² (± S.E.) on the upper surface of leaflets in the top, middle and bottom strata at front and back canopies of the three-year old oil palm with various concentrations of AFX Fogging Solution (AFX) applied by Agrofog® AF 35. In each graph, bars followed by the same letter are not significantly different ($P > 0.05$) according to ANOVA and LSD.	113
6.6	Number of droplets/cm ² (± S.E.) on the upper surface of leaflets at the top, middle and bottom strata in the front and back canopies of the three-year old oil palm with the application of 15% of AFX by Agrofog® AF 35. In each graph, bars followed by the same letter are not significantly different ($P > 0.05$) according to ANOVA and LSD.	118
7.1	Various droplet densities deposited by a knapsack mistblower (Solo® Master 412). The densities are given scores of 1 (bottom) to 6 (top).	135
7.2	Laboratory efficacy of <i>Bt</i> on the L3 of <i>M. plana</i> from treatments applied by Solo® in the field at various concentrations of Dipel® ES and levels of DD. Vertical lines are standard errors of means.	137

7.3	Laboratory efficacy of <i>Bt</i> on the L5 of <i>M. plana</i> from treatments applied by Solo® in the field at various concentrations of Dipel® ES and levels of DD. Vertical lines are standard errors of the means.	137
7.4	The layout of spray application by Solo® on the three-year old oil palm.	143
7.5	The trend of deposition rates on upper surface of the foliage at frond sections: proximal, middle and distal, and at the top, middle and bottom strata of three year-old oil palm after being sprayed with Solo® Master 412 knapsack mistblower at four different durations of spray time. In each graph, the four lines represent the duration of spray time. The symbols: X = 1.0 minute, Δ = 1.5 minutes, ◇ = 2.0 minutes and □ = 2.5 minutes. Vertical lines indicate standard errors of mean number of droplets/cm ² .	147
7.6	The trend of deposition rates on lower surface of the foliage at frond sections: proximal, middle and distal, and at the top, middle and bottom strata of three-year old oil palm after being sprayed with Solo® Master 412 knapsack mistblower at four different durations of spray time. In each graph, the four lines represent the duration of spray time. The symbols: X = 1.0 minute, Δ = 1.5 minutes, ◇ = 2.0 minutes and □ = 2.5 minutes. Vertical lines indicate standard errors of mean number of droplets/cm ² .	148
7.7	General spray deposition profile at various sections in a quadrant of three-year old oil palm canopy after being sprayed with Solo® Master 412 knapsack mistblower. The darkest shade received the highest droplet deposition rates.	153
7.8	The trend of deposition rates at upper surface of leaflets at frond sections: proximal, middle and distal, in top, middle and bottom strata of three-year old oil palm after being sprayed by Solo® Master 412 knapsack mistblower at various durations of spray time and two restrictor settings. The symbols: Δ = Restrictor 2; 1.0 minute, ◇ = Restrictor 2; 1.5 minutes and □ = Restrictor 1; 2.5 minutes. Vertical lines indicate standard errors of means number of droplets/cm ² . Sources obtained from Appendix 7.26.	161